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# EXPERIMENTAL INVESTIGATION ON INFLUENCE OF PROCESS PARAMETERS IN SELECTIVE LASER SINTERING ON ROUNDNESS USING TAGUCHI MEDTHOD

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***ABSTRACT***

***Additive Manufacturing is emerging latest trends, in todays industrial needs. The 3D model is built by using the Catia V5 and exported to Rapid Prototyping machine where the file is saved by. stl extension and the file repair was done by removing the facets using magics software. The 3D model is sliced into layers and build layer by layer using PA2200 material in powder form and sintered with $co_2$ laser by controlling the process parameters. This research investigates the effect of the roundness of the prototype model built on Rapid Prototyping machine by optimal selection of process parameters like laser power, layer thickness and temperature by Taguchi design of experiments approach $L_9$ Orthogonal array was selected lower-the-better signal-to-noise S/N ratio. Analysis of Variance (ANOVA) with regression model is also conducted and most influential parameter in decreasing order Laser power, Layer thickness, and temperature were obtained and the prototypes are tested on CMM (coordinate measuring machine) both the experimental and model prediction results are within close tolerance of +/- 0.029 (29 microns) on the roundness.***

***KEYWORDS: Additive Manufacturing, 3D model, Rapid Prototyping Machine, orthogonal array, ANOVA, S/N ratio, sintering, PA2200, CMM, tolerance***

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**Original Article**

## INTRODUCTION

Rapid prototyping is an Additive Manafacuring technique in which the solid model is built by addition of material where the model is built using Catia V5 software and saved with the file extension. iges or. Step and exported to the Rapid prototyping machine where the file is converted to. stl. After converting to. stl is the file is repaired by using another software magics all the facets are removed and then the model is sliced into layers with layer thickness and build layer by layer using polyamide material PA2200 in powder from and sintered by $co_2$ laser This technology is used for various materials plastics, metals, copper, aluminium etc., [1]. The principle of selective laser sintering process is the powder layer is placed on the bed of Rapid prototype machine with the help of rollers and sintered by laser and the bed is moved down by an amount of layer thickness and one more layer is placed over the previous sintered layer and thus the model is built layer by layer [5] as shown in the figure. Selective laser sintering process is used for producing functional parts with in short period of time and cost and ready to market the product where the ideas are easily implemented and prototype models are produced [3-6] The parts produced have less surface finish and roundness lot of work done on surface finish but less work is done on roundness so the present research work this paper is focused on roundness by varyng the process parameters using

taguchi design of experiments of orthogonal array and tested on CMM (Cordinate Measuring Machine).

## LITERATURE SURVEY

Mayer [10] done work on surface methodology process and product optimization using design of experiments [1] Pandey and Senthilkumaram have done on part accuracy and shrinkage influence by process parameters of the selective laser sintering process [2] Sercombe, T, B Hopkinson has done on metals like aluminium about part shrinkage and accuracy [7] Ning, Y.; Wong, Y. S.; Fuh, worked on minimized the build errors in metals [8] Wenbin, H.; Tsui, L. Y.; Haiqing done staircase effect induced by part shrinkage in RPT machine. [9]. Ning, Y.; Fuh, J. Y. H.; Wong, Y. S.; Loh, H. T. Worked on the parameter selection system for the direct metal laser sintering process. [3] Raghunath, N Pandey done work on improving the accuracy through shrinkage modeling by using Taguchi method in the selective laser sintering process [12] Anish Sachdeva & Sharanjit Singh done on surface roughness by using sls. After analyzing the literature survey accuracy of the part is dependent process parameters like power, scan speed, layer thickness, temperature, etc. highly related to the shape and size of the components produced by the selective laser sintering process. The present research work is on the roundness by optimizing the process parameters like laser power, layer thickness and bed temperature enhance the quality of the component produced by sls.

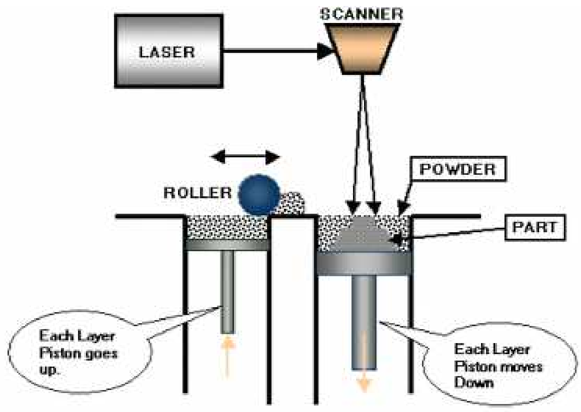


**Figure 1: Principle of Selective Laser Sintering Process**

**Figure 2**: **Rapid Proto typing Machine**

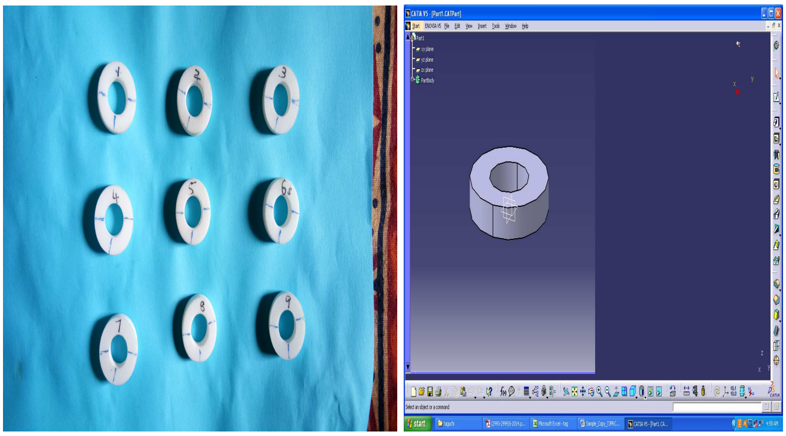

**Figure 3 and 4: Samples of sls Process and 3D CAD Model**

**EXPERIMENTATION**

The parameter settings like laser power, layer thickness and temperature beds at different levels are shown in table1. The reasons roundness is shown in table 2. A total of nine (9) experiments were conducted, using taguchie design of experiments approach orthogonal array and tested using CMM (Coordinate Measuring Machine). The material used to build the prototypes is Polyamide PA2200, in the powder form and sintered by $co_2$ laser with controlled process parameters. All the fabricated prototypes, using selective laser sintering process, by varying the process parameters built are shown in the figure 3 and the 3D model is created by using Catia V5 Shown figure 4.

**Table 1: Levels of Process Parameters**

| PARAMETERS | DESIGNATION | UNITS | LEVEL 1 | LEVEL 2 | LEVEL 3 |
|---|---|---|---|---|---|
| LASER POWER | P | WATT | 67 | 68 | 70 |
| LAYER THICKNESS | L | MICRONS | 100 | 110 | 120 |
| TEMPERATURE | T | DEGREE CEBTIGRA DE | 174.7 | 175 | 176 |

**Table 2: Experimental Results of Orthogonal Arrray of $L_9$ for Roundness**

| EXPEREIMENT RUN | LASER POWER | LAYER THICKNESS | TEMPERATURE | ROUNDNESS |
|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 0.0954 |
| 2 | 1 | 2 | 2 | 0.0388 |
| 3 | 1 | 3 | 3 | 0.0458 |
| 4 | 2 | 1 | 2 | 0.0673 |
| 5 | 2 | 2 | 3 | 0.0784 |
| 6 | 2 | 3 | 1 | 0.0548 |
| 7 | 3 | 1 | 3 | 0.0383 |
| 8 | 3 | 2 | 1 | 0.0292 |
| 9 | 3 | 3 | 2 | 0.0524 |

**Table 3: S/N Ratio of Each Parameter and Level for Roundness**

| Parameter | Level | Experimental Run | Mean Roundness Microns | S/N Ratio dB | Average S/N Ratio dB | Delta (max-min) | Rank |
|---|---|---|---|---|---|---|---|
| | | 1 | 0.0954 | 20.409 | | | |
| | 1 | 2 | 0.0388 | 28.223 | 25.138 | | |
| | | 3 | 0.0458 | 26.782 | | | |
| | | 4 | 0.0673 | 23.439 | | | |
| P | 2 | 5 | 0.0784 | 22.113 | 23.592 | 4.62 | 1 |
| | | 6 | 0.0548 | 25.224 | | | |
| | | 7 | 0.0383 | 28.336 | | | |
| | 3 | 8 | 0.0292 | 30.692 | **28.213** | | |
| | | 9 | 0.0524 | 25.613 | | | |
| | | 1 | 0.0954 | 20.409 | | | |
| | 1 | 4 | 0.0673 | 23.439 | 24.061 | | |
| | | 7 | 0.0383 | 28.336 | | | |
| | | 2 | 0.0388 | 28.223 | | | |
| L | 2 | 5 | 0.0784 | 22.113 | **27.009** | 2.94 | 2 |
| | | 8 | 0.0292 | 30.692 | | | |
| | | 3 | 0.0458 | 26.782 | | | |
| | 3 | 6 | 0.0548 | 25.224 | 25.873 | | |
| | | 9 | 0.0524 | 25.613 | | | |
| | | 1 | 0.0954 | 20.409 | | | |
| | 1 | 6 | 0.0524 | 25.224 | 25.441 | | |
| | | 8 | 0.0292 | 30.692 | | | |
| | | 2 | 0.0388 | 28.223 | | | |
| T | 2 | 4 | 0.0673 | 23.439 | **25.758** | | |
| | | 9 | 0.0524 | 25.613 | | 0.31 | 3 |
| | | 3 | 0.0458 | 26.782 | | | |
| | 3 | 5 | 0.0754 | 22.113 | 25.743 | | |
| | | 7 | 0.0383 | 28.336 | | | |
| | | **sum** | 1.4958 | | 230.828 | | |
| | | **Average** | 0.0554 | | 25.6475 | | |

**Table 4: For Maximum Andminimum Influence Anom (Analysis of Mean)**

| LEVELS | POWER | LAYER THICKNESS | TEMPERATURE |
|---|---|---|---|
| LEVEL1 | 0.180 | 0.201 | 0.162 |
| LEVEL2 | 0.200 | 0.146 | 0.158 |
| LEVEL3 | 0.119 | 0.153 | 0.179 |
| RANGE | 0.081 | 0.055 | 0.021 |

## RESULTS AND DISCUSSIONS

After the results obtained from the experiements taguchi quality indes lower – the - better S/N ratio, in dB was used to find the optical process parameter, Lower=the=better.

**S/N ratio = $-10\log_{10}$ (1/n $\Sigma Y^{2)}$)** n= recurrence =1 and Y is the measured roundness, for each trial.

The table provides the calculated values of S/N ratio and the average S/N ratio, for all the parameters and its levels. To achieve the roundness of polyamide parts produced by sls process, the maximum of the S/N ratio to reduce the loss function and better the quality, and the optimal process parameters are obtained shown in the table. The figures 5-13 shows the main effect of process parameters, on the S/n ratio at all levels. Optimization of control factors ANOM (Analysis of Mean) at all the three levels, for each factor.

**Laser Power Level 3 70 watts Layer Thickness level 2 110 Microns Temperature level 2 175 Degree Centigrade as shown in figures**

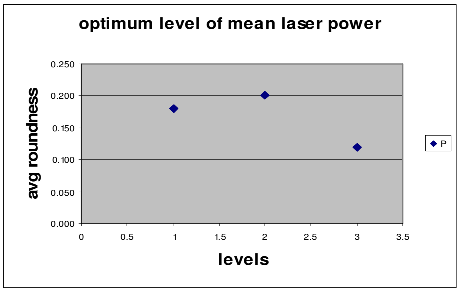


**Figure 5: Laser Power**

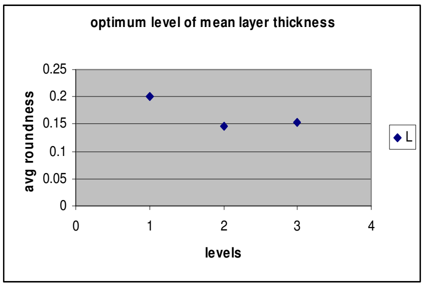


**Figure 6: Layer Thickness**

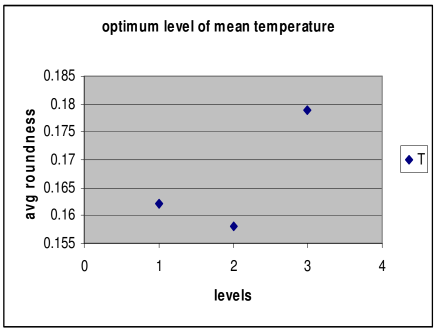


**Figure 7: Temperature T**

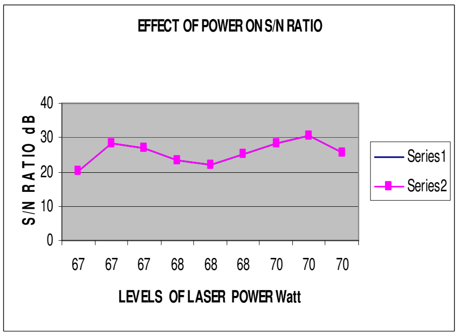


**Figure 8: S/N ratio vs Laser Power**

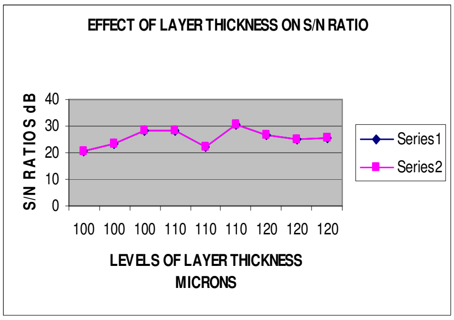


**Figure 9: S/N ratio vs Layer Thickness**

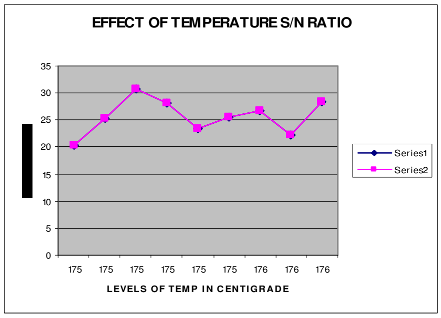


**Figure 10: S/N ratio vs Temperature**

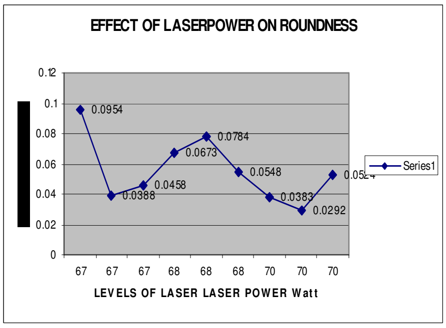


**Figure 11: Roundness vs Laser Power**

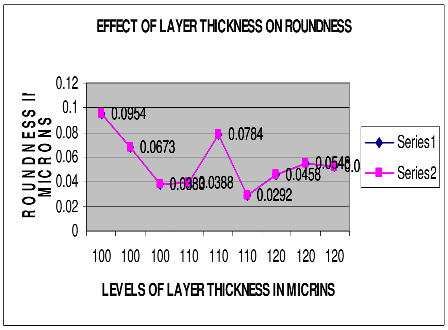


**Figure 12: Roundness vs Layer Thickness**

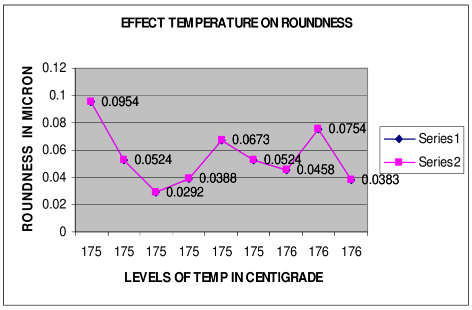


**Figure 13: Roundness vs Layer Thickness**

**ANOVA (Analysis of Variance) for ROUNDNESS**

**Table 5: Analysis of Variance**

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| LP | 2 | 0.001170 | 0.000585 | 0.66 | 0.604 |
| LT | 2 | 0.000592 | 0.000296 | 0.33 | 0.751 |
| T | 2 | 0.000082 | 0.000041 | 0.05 | 0.956 |
| Error | 2 | 0.001782 | 0.000891 | | |
| Total | 8 | 0.003626 | | | |

**Table 6: Model Summary**

| S | R-sq | R-sq (adj) | R-sq (pred) |
|---|---|---|---|
| 0.0298514 | 50.85% | 0.00% | 0.00% |

**Table 7: Coefficients of Regression**

| Term | Coef | SE Coef | T-Value | P-Value | VIF |
|---|---|---|---|---|---|
| Constant | 0.05560 | 0.00995 | 5.59 | 0.031 | |
| LP | | | | | |
| 1 | 0.0044 | 0.0141 | 0.31 | 0.784 | 1.33 |
| 2 | 0.0112 | 0.0141 | 0.80 | 0.508 | 1.33 |
| LT | | | | | |
| 1 | 0.0114 | 0.0141 | 0.81 | 0.503 | 1.33 |
| 2 | -0.0068 | 0.0141 | -0.48 | 0.677 | 1.33 |
| T | | | | | |
| 1 | 0.0042 | 0.0141 | 0.30 | 0.794 | 1.33 |
| 2 | -0.0028 | 0.0141 | -0.20 | 0.862 | 1.33 |

**Table 8: Regression Equation**

| | | |
|---|---|---|
| **Roundness** | = | 0.05560 + 0.0044 LP_1 + 0.0112 LP_2 - 0.0156 LP_3 + 0.0114 LT_1 - 0.0068 LT_2 - 0.0046 LT_3 + 0.0042 T_1 - 0.0028 T_2 - 0.0014 T_3 |

Roundness from the regression model, in microns 0.0172.

**Confirmation Test**

This research paper is to validate the model equation, confirmation experiment and S/N method were adopted at optimum level and the table, shows the experimental and predicted values are compared at optimum settings, on the roundness.

The predicted value of roundness is calculated from the of S/N ratio, at optimum settings.

$S/N_{predicted} = S/N_{mean} + ( S/N_i - S/N_{mean})$ 25.652 = $-10\log Y^2$ Y= 0.052 microns.

**Predicted Model**

The predictive model is constructed from the results of the orthogonal array analysis and it is formed by the optimum level of contribution of each factor related to deviation from overall mean is,

$Y(P,L,T) = Y_{mean} + (Y_{mean\ P} - Y_{mean}) + (Y_{mean\ L} - Y_{mean}) + (Y_{mean\ T} - Y_{mean})$ at optimum parameters.

$Y(P_3 L_2 T_2)$ = 0.0556 + (0.039 -0.0556) + 0.048-0.0556) + (0.052 -0.0556)

= 0.0296 approx 30 microns.

Comparison between the experimental value, regrssion value, predicted S/N ratio and mean value

**Table 9: Comparisson Experimental and Predicted Values**

| Parameter | Laser Power | Layer thickness | Temperature | Experimental value | Predicted S/N value | Mean value | Regression Value |
|---|---|---|---|---|---|---|---|
| Optimal setting | 70 watts | 110 microns | 175ºC | 0.0292 | 0.052 | 0.0296 | 0.0172 |

## CONCLUSIONS

The influence of process parameters on the roundness of polyamide parts, built by a selective laser sintering process, by Taguchi design of experiments $L_9$ orthogonal array approach and the roundness of the parts was found out by experimental value, S/N ratio, regression value and mean value it was found that, close tolerance 30-55 microns were obtained, with the optimization process parameters.

- The optimal parameters Laser power has maximum influence, layer thickness medium and temperature minimum influence.
- Confirmation model results roundness, approx to 30 microns.
- Experimental value on roundness with optimal process parameter is about 29 microns.
- S/N ratio value on roundness is 52 microns.
- The results after comparison, there are variation 25 microns from mathematical and experimental values.

## ACKNOWLEDGEMENT

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